Remote instrument diagnosis on the Internet

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Abstract:
First AID (Automated Instrument Diagnostics) is a fault-diagnosis expert system that is based on an in client architecture. This expert system uses generic tools such as Web browsers to aid service enginee diagnosing the faults in LEO scanning electron microscopes (SEMs). The system lets engineers acqui directly from the SEM, diagnose inaccurate behavior and remedy inappropriate instrument settings.

Index Terms:
scanning electron microscopes; fault diagnosis; diagnostic expert systems; Internet; automatic test sof telemetry; remote instrument diagnosis; Internet; First AID; Automated Instrument Diagnostics; fault-expert system; information client architecture; generic tools; World Wide Web browsers; service engi scanning electron microscopes; remote fault diagnosis; information acquisition; inaccurate behavior; i instrument settings

SEARCH RESULTS [PDF Full-Text (1004 KB)] PREVIOUS NEXT

Remote Instrument Diagnosis on the Internet

Nicholas H.M. Caldwell, Bernard C. Breton, and David M. Holburn, University of Cambridge

THIS EXPERT SYSTEM USES GENERIC TOOLS SUCH AS WEB BROWSERS TO AID SERVICE ENGINEERS IN REMOTELY DIAGNOSING THE FAULTS IN LEO SCANNING ELECTRON MICROSCOPES. THE SYSTEM LETS ENGINEERS ACQUIRE INFORMATION DIRECTLY FROM THE SEM, DIAGNOSE INACCURATE BEHAVIOR, AND REMEDY INAPPROPRIATE INSTRUMENT SETTINGS.

AS THE WEB BECOMES A MORE stable avenue for idea exchange, researchers have begun to explore more ways to use it in knowledge acquisition. In one such effort, researchers in Cambridge University's Engineering Department are collaborating with LEO Electron Microscopy Ltd., to explore how knowledge-based systems can improve operator interaction with a scanning electron microscope, or SEM. A product of that work is First AID (Automated Instrument Diagnostics), a fault diagnosis expert system that is based on an information client architecture. The sidebar "How information clients differ from knowledge servers" explains more about this type of architecture and how First AID differs from existing systems. Like other information-client-based systems, First AID can access one or more Internet sites to obtain pertinent information or data, which it then uses to assist inference. This contrasts to the knowledge-server architectural approach,[1] in which the system resides on the network and reasons on behalf of multiple remote clients that provide the interface for remote users.

In this article, we describe an application of First AID for the LEO 400 series, PC-based SEMs, which run on Microsoft Windows. First AID lets microscope service engineers remotely diagnose LEO's SEMs, thereby avoiding costly travel to customer sites. As far as we know, this is the first time the Internet has been used for diagnosis in this fashion. A recent assessment by service engineers indicates that the First AID system can be of major benefit in the diagnostic task for average and expert engineers alike.

Why remote diagnosis?

A scanning electron microscope is a sophisticated scientific instrument that, in advanced versions, is fully computer-controlled. Three decades of commercial manufacturing has led to a steady evolution of SEM sophistication. This, combined with increased manufacturer competition and a shrinking market, have created a critical need for maintenance support.

However, SEM fault diagnosis suffers from two main disadvantages. First, there are relatively few experts. The primary reason is that a service engineer is expected to repair any SEM—from the oldest surviving instrument, possibly 30 years old, to the most modern machines. Acquiring and retaining expertise for this broad range of SEMs is difficult because there are only so many instruments of a particular model.

Second, SEM manufacturers are geographically distant. For example, SEM technical support for LEO is distributed between the dual company headquarters at Cambridge (UK) and Oberkochen (Germany) and the local service agencies in various countries. The local service agencies provide the first level of customer support, referring more difficult cases to headquarters. Thus a telephone diagnosis and subsequent treatment can require a site visit, with spare parts being ordered from the UK in some cases. Misdi-

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agnosis, which involves taking wrong or unneeded components to a site, costs the company time and money and the customer unnecessarily prolonged downtime.

Telephone diagnosis is also unsatisfactory because the SEM is a visual instrument, with many symptoms appearing as imaging defects. To communicate an imaging defect, the customer must describe the symptom in great detail verbally. The ambiguity of natural language becomes even more of an obstacle when one or both parties must use a foreign language. Traditional diagnostic methods are also unsuitable for correcting another possible cause of malfunction—an incorrect instrument parameter setting. In this situation, the SEM appears to be malfunctioning because some sequence of actions has caused it to reach an inappropriate combination of instrument parameters (we describe an example later). In the traditional mode of diagnosis, the customer must produce an exhaustive list of instrument-setting parameters, which is time-consuming.

System requirements and overview

Given these remote-diagnosis requirements, any SEM fault-diagnosis system must provide the service engineer with the knowledge of the best domain experts as well as accurate image and instrument parameter settings from the SEM itself.

To meet the first requirement, we needed an expert system. To meet the second requirement, we needed an expert system that could acquire information directly from the SEM, remotely conduct diagnoses, and remotely remedy inappropriate instrument settings.

At the outset, we knew that a fault-free instrument was a prerequisite for optimizing SEM operation and that we would need the same expertise for both SEM operation and fault diagnosis. We also needed a more flexible environment than, say, an expert shell, because the remote-control software and future systems would be embedded in the SEM itself. Finally, the research costs for Cambridge University and the final deployment costs to LEO had to be as low as possible. These constraints (among others) led us to develop First AID from scratch using Logic Programming Associates' Win-Prolog (*http://www.lpa.co.uk*).

We conducted the initial knowledge acquisition for First AID over four weeks. During that time, we drew knowledge primarily from service manuals and archived case histories. We then developed protoheuristics and submitted them to domain experts to evaluate and validate. We later expanded this knowledge base through informal interviews with the domain experts and by mining relevant documents.

The next step was to design a rule-based representation that simulates the engineer's

How information clients differ from knowledge servers

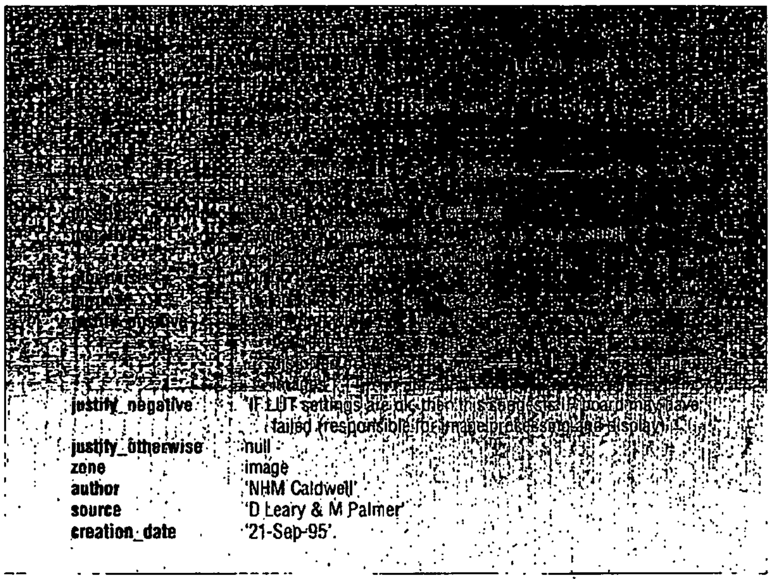
The information-client architecture is a mirror of the more familiar knowledge-server architecture. In knowledge-server architectures, the system resides on the network and multiple clients access it remotely. The inferences are derived at the server site, while input submission and output display is handled on the client site (using Java applets in Henrik Eriksson's implementation[1]). This architecture is appropriate for public expert systems, which could be used, say, to off-load help desks by making the expertise available on the Internet.

Expert system shells have recently become commercially available that adopt the knowledge-server approach. Wren (Exsys Web Runtime Engine) lets knowledge bases (implemented using Exsys development tools) be transferred onto Web servers so that users can access the resulting expert systems via the Web. Wren (*http://www.exsysinfo.com/Wren/wren.html*) is a purely HTML-based implementation that uses CGI (Common Gateway Interface) forms to ask the user questions, present conclusions, and justify its reasoning.

An information-client-based system, in contrast, accesses one or more Internet sites to obtain pertinent information or data, which it then uses to assist inference. These systems have many possible applications in remote diagnosis, sensing, monitoring, and control. The astronomical community has implemented several systems for long-range remote control of Earth-based telescopes, some using dedicated networks,[2] and others using the Web.[3,4] The aim of these systems is to alleviate the problems caused by the geographical separation between modern observatories and potential researchers. Some of these telescope systems prevent inappropriate or dangerous instrument maneuvers by validating the requests against a "virtual microscope" model of the instrument. Although these systems would benefit from a knowledge-based approach, expert systems have not been connected to the remote-control facilities. An expert system has been developed and deployed to monitor telemetry autonomously from a space-based instrument.[5] In contrast to First AID, this system uses a proprietary telemetry-reception module rather than Web-based techniques for data acquisition. A theoretical architecture was also proposed for multiple instrument diagnosis using "telemaintenance servers" to handle simple faults with automatic escalation to remote maintenance centers where neural network or knowledge-based systems might be used to resolve the problem.[6] First AID is currently a reactive system to diagnose and remedy faults once they have occurred. However, the LEO control software could be enhanced to transmit regular logs to service headquarters for proactive fault detection. Knowledge-based SEM monitoring is a natural offshoot of the current work

References

1. H. Eriksson, "Expert Systems as Knowledge Servers," *IEEE Expert*, Vol. 14, No. 3, May/June 1996, pp. 14–19.
2. J.G. Cohen, L. Bergman, and P.L. Shopbell, "A High Speed Network for Remote Observing from Caltech with the Keck Telescope," *Proc. Astronomical Data Analysis Software and Systems V*, Astronomical Soc. of the Pacific, San Francisco, 1996, pp. 376–379.
3. F. Economou et al. "Remote Eavesdropping with the World Wide Web," *Proc. Astronomical Data Analysis Software and Systems V*, Astronomical Soc. of the Pacific, 1996, pp. 384–391.
4. J. Baruch and M. Cox, "Remote-Control and Robots: An Internet Solution," *Computing & Control Eng. J.*, Vol. 7, No. 1, 1996, pp. 39–45.
5. L. Wong et al., "Development and Deployment of a Rule-Based Expert System for Autonomous Satellite Monitoring," *Proc. Astronomical Data Analysis Software and Systems V*, Astronomical Soc. of the Pacific, 1996, pp. 440–446.
6. A. Laugier et al., "Remote Instrument Telemaintenance," *Computer Methods & Programs in Biomedicine*, Vol. 50, No. 2, 1996, pp. 187–194.



```
justify_negative      : 'IF LUT settings are ok, then this suggests [illegible] board may have
                          failed (responsible for image processing and display)'
justify_otherwise     : null
zone                  : image
author                : 'NHM Caldwell'
source                : 'D Leary & M Palmer'
creation_date         : '21-Sep-95'.
```

Figure 1. A sample rule in the formalism used to simulate the engineer's reasoning from a set of initial symptoms to any probable causes. The reasoning is done as a series of tests. In this case, the rule is applied to determine why the image is not satisfactory.

reasoning approach. Figure 1 gives a sample rule in this representation, which determines why an image is unsatisfactory. Reasoning begins with a set of initial symptoms and ends with any probable causes. It is simulated via a series of tests that weed out possible causes.

This representation is a variation of the traditional rule format:

- The `if` slot contains (in this case) a set of symptoms.
- The `action` and `request` slots propose an identical test to determine the possible cause of the reported symptom. A nonnull `action` slot means that First AID can conduct the applicable test remotely by calling the relevant procedure.
- The `positive`, `negative` and `otherwise` slots contain the conclusions First AID can draw from a test. The `otherwise` slot provides conclusions when the test has failed.
- The `justify_` slots contain brief explanations for the inferences.
- The `purpose` slot contains the reason for including the rule.
- The `zone` slot classifies rules according to the location of the perceived symptom or actual fault.

The remaining slots are solely for maintenance.

We also developed a small set of metarules to control forward chaining. The metarules inspect the contents of the blackboard to determine the highest priority hypotheses, which First AID then uses to select the next rule to fire.

To implement First AID we combined rapid prototyping with informal user-participative design techniques. We used a demonstration prototype to provide the proof of concept for our expert system approach. Subsequent prototypes incorporated many suggestions from engineers to improve usability—from minor improvements, such as rewording explanations and user interface labels to make them easier to understand, to major issues involving expert system security, such as suggesting password protection for certain system functions.

Because the knowledge base has only 185 rules (at the time of publication) and because we planned to slowly and incrementally expand it, we have been able to manually verify it and locate any possible logical anomalies. We have also subjected the inference engine and the user interface to rigorous testing to ensure sensible and correct behavior. (Once LEO takes over knowledge-base expansion and maintenance, the staff will need an automated knowledge-base assistant to support those tasks.) Three domain experts have validated the knowledge base for accuracy, with the leading expert conducting informal validation tests on the working system. We describe First AID's design and implementation in greater detail elsewhere.[2]

Remote-control system

Figure 2 shows First AID's remote-control system for the LEO 400 series SEMs. The system has three logical components: the SEM site, the remote site, and the intervening network.

At the *SEM site* (left rectangle in the figure), the hypertext documents comprise the interface to the remote SEM operator. We have developed software using generic tools such as Netscape, which provides a remote-control user interface for SEMs via the Web.[3] We extended this software using Java applets so that it is suitable for remotely monitoring instrument parameters as well. The Web server provides the hypertext documents to the remote operator's Web browser. The Web server transfers requests from the remote operator to LEODDE. LEODDE is a Common Gateway Interface program that translates requests into dynamic data-exchange requests so that the SEM control software's DDE interface can understand them. Dynamic data exchange, which Windows supports, lets applications executing within a DDE environment communicate with each other by continuously and automatically exchanging data.

The SEM control software then acts on the requests and passes the results back through the chain to the Web server, which returns them to the remote operator. We adapted Cornell University's CUSeeME shareware video-conferencing package[4] to provide dynamic image transfer from the SEM to the remote operator.

At the *remote site* (far right rectangle in the figure), the service engineer needs a graphical Web browser, such as Netscape Navigator or Internet Explorer, so that he can connect to the SEM Web server. He also needs a copy of CUSeeME so that he can receive dynamic images. He can receive static images of up to 1024 × 768 (the SEM's maximum screen resolution) through the Web browser alone. The Web browser and CUSeeME then handle all transfer of information and requests over the intervening network.

By using generic tools such as Web browsers and servers, we could rapidly develop software at minimal cost and yet pro-

vide proven networking functionality that is suitable for access via both local area networks and the Internet.

Integration with the Web

When the remote-control infrastructure was stable enough, we began to look at how we could make First AID an information client, as described earlier. Spyglass Inc. has produced a Software Developers Interface (*http://www.spyglass.com:4040/newtecnology/integration/iapi.html*) for application programmers to couple the networking facilities of standard Web browsers with their software. Netscape Communications has implemented a slightly modified version of this for the Navigator browser as a DDE interface (*http://search.netscape.com/newsref/std/ddeapi.html*). Because Win-Prolog also supports DDE protocols, we decided to use this mechanism to manipulate Netscape and hence the remote-control software.

We began by exploiting the minimum required Netscape functions:

- start and terminate Netscape,
- load Web pages,
- automatically fill in forms and click icons on Web pages,
- load files, and
- retrieve returned data.

Users can launch any program in Windows using a simple Prolog predicate. They can then retrieve returned data for automatic processing by saving it as a file for later parsing. To provide the other functions, we had to use some DDE topics (a topic defines a DDE conversation). The asynchronous loading nature of Netscape poses several pitfalls and seemingly useful DDE topics are not guaranteed to return accurate information about the state of a Web-page download. Similar difficulties arise when interfacing with other browsers and AI software. Indeed, we were frustrated in recent attempts to interface First AID with Microsoft's Internet Explorer because Explorer supports only a fraction of Spyglass's Software Developer's Interface.

The key DDE topics we have used are `WWW_Exit`, `WWW_OpenURL`, and `WWW_ShowFile`. The last two require the system to provide the URL of a Web page or the location of a file as well as the identifier of the Netscape window to display the download,

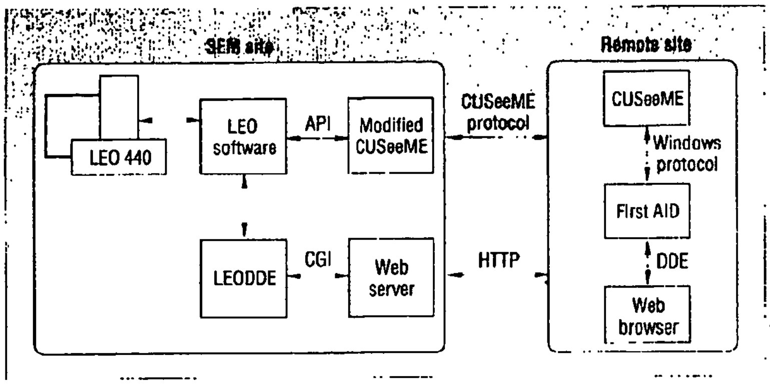


Figure 2. How First AID fits into a control system for remotely diagnosing the LEO 400 series scanning electron microscopes. The SEM site is the location of the microscope. The remote site is the location of the SEM service engineer. Much of the control system uses generic tools like Web browsers and servers. CUSeeME allows the engineer to see dynamic images for more effective fault diagnosis.

the manner in which the download is to be accomplished, and so on. The `WWW_ OpenURL` topic can also be used to open Uniform Resource Indicators (URIs), which are the HTML tags associated with forms and icons. Although Win-Prolog supports long atoms (1,024 characters in the current version), DDE requests as Microsoft defines them can have at most only 256 characters. This can become a problem because a lot of information must be encoded in one DDE request to fill in a form: the URL, the form's URI, the mapping of data to form variables, and the necessary control information for Netscape.

The first pitfall with using DDE to control Netscape is that communication will succeed only if Netscape is actually running. Fatal exceptions will occur if the system makes a DDE request before Netscape has completely started, which includes a fully loaded user starting page. Our solution is to provide an error handler to catch the error and resend the request.

The second pitfall stems from the difference in the time it takes for a Web download to complete and the Prolog program to send a series of DDE requests. A DDE request to load a specific Web page followed by a second request to click on an icon on that Web page before it has fully loaded can cause a fatal DDE error in Win-Prolog or a general protection fault in Netscape or both. This occurs because Netscape is trying to process a request it cannot as yet understand. Because dependent DDE requests can be safely processed only after the entire Web page has loaded, we force First AID to accept DDE acknowledgments about the status of the download. We do this by registering Win-Prolog as a DDE server for the `WWW_ URLEcho` topic when the `WWW_RegisterURLEcho` topic is invoked. (The `WWW_BeginProgress`, `WWW_MakingProgress`, and `WWW_EndProgress` topics are not required to provide accurate information). Thus Win-Prolog receives a message from Netscape every time a file is loaded, which includes a message for each inline image and complete Web page. First AID collects and processes these *callbacks* and transmits dependent DDE requests only if the number of received callbacks equals the expected number for the given Web page.

The third pitfall is that incorrect HTML syntax can produce variable numbers of callbacks, and the user cannot see this discrepancy. We have validated the relevant Web documents using HTML syntax checkers.

How the Web is used

Careful use of DDE protocols—although important—cannot produce an effective information-client-based expert system. First, it is clearly not beneficial to suspend all other expert system functions while waiting for a Web page to download. Instead, control should return to the user and the inference engine as soon as possible, with the handler processing DDE callbacks in much the same way as it would other low-level interruptions. It is also not efficient to have to wait for cooperating programs to report results from remote tests. The SEM operator can usually communicate the test results to the service engineer verbally via telephone faster than he can transfer them over the Internet.

Figure 3 shows the main consultation screen, which is the primary screen used during diagnosis. The buttons on the bottom half reflect choices the remote operator has in using First AID:

- *What?* lets the engineer determine the current inferences and facts the system believes.
- *How?* provides a trace of which rules were involved in deriving particular inferences.
- *Why?* informs the engineer of the system's purpose in asking a question (including which conclusions will be drawn on the basis of the engineer's response).
- *Justify* provides a concise explanation to support a specific conclusion.
- *Explain* refers the engineer to relevant sections of the service manual.
- *Rule* lets the engineer view complete rules stored in the knowledge base.
- *Purpose* provides a brief summary of a specific rule's aim.
- *Volunteer* lets the service engineer suggest hypotheses to First AID.
- *Overrides* lets the service engineer remove existing hypotheses, tell the system to ignore them until further notice, or increase their priority. Both this and the volunteer facility are essential in guiding the consultation because improved diagnostic information and unpredictable network transfer mean that the service engineer will make inferences spontaneously or later recognize erroneous ones.
- *Gripe* is an anonymous feedback mechanism that lets the engineer record criticisms and suggestions for system improvement.

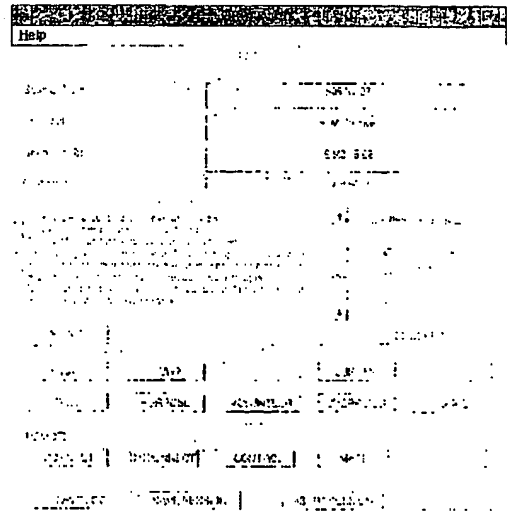


Figure 3. First AID's main consultation screen.

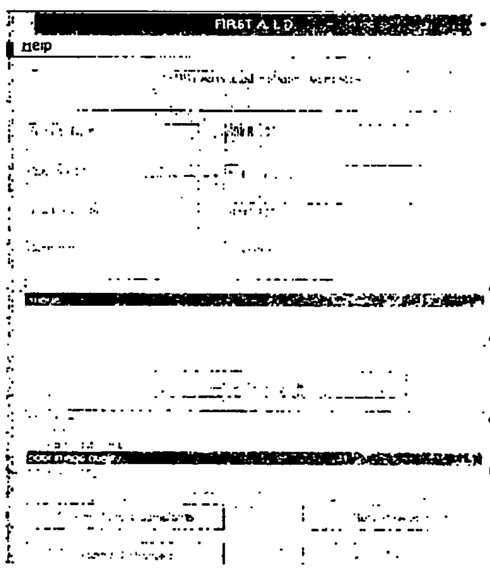


Figure 4. What happens when the engineer selects an image-related symptom in the setup window. The text window represents the list of possible image complaints.

engineer can manually invoke via the *Actions* button. Most rules in the knowledge base include a diagnostic test. About half these rules can be conducted remotely. The others involve degenerate cases such as the inability to start the LEO control software because the software is corrupt or because an instrument must be physically adjusted.

Whenever the inference process reaches a rule that does include a remote test and the SEM in question has the appropriate remote-control setup, the user can perform the test in either the manual or semiautomatic mode. Manual mode is the default when the SEM is not accessible through the Internet. It can also be used if the SEM operator does not permit Web access or when there are network problems. Semiautomatic mode explains the command sequences to be invoked and their proper order. This does not commit the engineer to conducting the remote test nor is he required to invoke all sequences. It simply lets him bypass commands if information is acquired directly from the customer or if he is experiencing network failures. He can repeatedly attempt any or all portions of a test before providing First AID with a definitive answer about the test.

First AID does not currently support an automatic mode, where the engineer would have no control over the remote-test procedure, but we plan to eventually implement automatic mechanisms for handling unexpected failures at the SEM site or within the network.

First AID in its current state uses the Web for four main tasks: remote control, remote imaging, remote testing, and online help. The remote control and imaging functions are accessible at any time during the main part of the consultation; the remote-test function is available only when a rule that permits such activity is fired.

The *Control* command button lets the service engineer access the standard remote-control user interface. The Web pages that provide the remote-test instruction sequences are not for human use because they have been optimized for download speed and minimal memory requirements. We are still attempting to acquire and reify the knowledge needed to emulate human experts in SEM operation. At present, it is more practical to use human expertise when full SEM operation is required.

The *Image* button lets the engineer acquire static images on demand from the SEM and display them in a Netscape window. It also lets him launch or terminate CUSeeME to view smaller, dynamic images.

Remote testing. The most important use of the Web is for remote testing, which the

Online help. The second most important use of the Web is to provide online help. Rather than incorporate help files directly within the expert system or provide help files using the traditional hypertext style of Microsoft Help files, we decided to produce online help as full HTML documents displayed within the Web browser. Text can thus be supported with images and, if necessary, audio or video clips.

This has several advantages. First, we need not burden First AID's design with the need to support vast quantities of factual information copied verbatim from service manuals and

maintained in multiple languages. Instead, First AID can concentrate on its main task, diagnosis. Second, help files can contain hypertext links, not only to local files on the engineer's PC but also to files on secure Web servers at LEO headquarters, thus allowing access to more information when needed. Finally, with Web-based help facilities, we can minimize the amount of domain-specific help that will accompany First AID. This means we can maintain First AID and let LEO personnel maintain the principal service manuals. Not only is LEO better suited for maintaining their manuals, but this arrangement also offers a significant security plus; an unprotected knowledge base with an extended explanation for each fault could otherwise fall into the hands of competitors. Maintaining security and preventing excessive overhead from update distributions are important considerations.

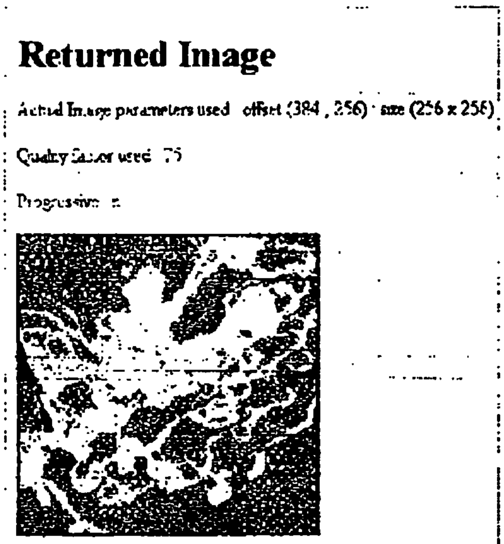


Figure 5. Static SEM image viewed through Netscape. The image, which the engineer can view while speaking to the customer on the phone, shows no gray levels.

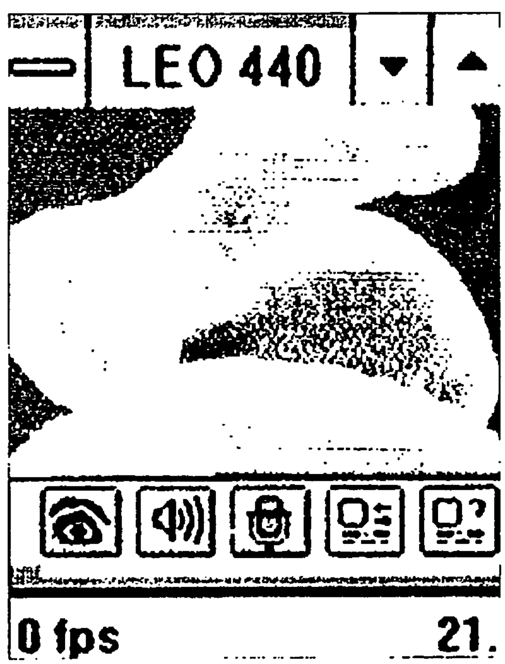


Figure 6. A dynamic version of the SEM image in Figure 5 after the service engineer has reset the instrument-setting parameters. Although the dynamic images shown through CUSeeME are smaller than the static images shown through Netscape, dynamic images show the engineer how corrective actions are affecting the microscope's image. In this case, the engineer can see that resetting the parameters has caused the image to recover its gray scale.

Sample consultation

To illustrate some of the Web-based functionality, we present a sample consultation in which a customer telephones a local service agency about a problem with his SEM. The service engineer starts the expert system (which brings up the startup window) and attempts to determine any symptoms. Unfortunately, neither the customer nor the service engineer are fluent in a common language, so the service engineer is able to determine only that the problem is some sort of imaging defect. From the setup window in Figure 4, he selects "image," which causes the set of image complaints to be displayed in the panel at the bottom of the window. He decides to select "poor image quality" as the best current description of the problem and finalizes this choice by selecting *confirm specific complaints*.

First AID updates its blackboard of beliefs and proceeds to the main consultation window. Rather than allowing the inference process to begin, the engineer decides to launch the Netscape browser by selecting Connect and requests a static image directly from the SEM, while maintaining a telephone conversation with the customer. Figure 5 shows the image he receives.

As he inspects the image in Figure 5, the engineer notices that it lacks any gray levels, which often suggests a failure in the image-processing circuit board. He next informs First AID of this symptom using the *volunteer* facility and asserts the belief complaint "image lacks gray levels." He signals First AID to proceed with inference by clicking on *proceed*. The metarules will seek a rule involving a volunteered fact before they seek rules involving inferred facts, so First AID fires the rule, "weirdimage1" (see Figure 1). The rule has an associated remote test, which the engineer decides to execute in semiautomatic mode. The test involves resetting the parameters in the display lookup table to their default values. The engineer activates the reset command and opens a CUSeeME client to view any change the reset command may cause in the image. Figure 6 shows the dynamic image he sees at this point. After the reset command propagates to the target SEM to reset the lookup table, the image recovers its gray scale. The customer, who is still on the phone, informs the engineer that the SEM is now fully operational. The engineer can see the changed image via the CUSeeME client. To conclude the consultation, he selects *Disconnect* to close Netscape and CUSeeME, and *Finish*, which prompts First AID to log the consultation. The entire consultation has probably taken only five minutes and cost a single telephone call.

Although this sample consultation seems simplistic, poor images have in reality been misdiagnosed as a board failure. The lookup table determines the correspondence between the discrete signal levels the SEM detector captures (and the succeeding signal-processing stages) and the set of shades or colors seen on the screen. As a result, it can radically affect perceived brightness, contrast, and so on. Expert microscopists use the display lookup table to produce the highest-quality images so that they can, for example, publish them in journals.

Unfortunately, an operator can all too easily save these changed lookup table settings inadvertently when shutting down the microscope. When he then restarts the microscope with a different sample, he might be

unable to acquire any worthwhile images. The control software will not indicate that non-standard parameters are being used, so unless the operator is familiar with the symptoms, it seems to him that the instrument has catastrophically failed.

In one case of misdiagnosis we know of, the manufacturer sent a senior engineer and a replacement board from the UK to the customer site. After a few minutes of operating the microscope, the engineer discovered the real cause, but because of the distances involved, he stayed the rest of the week, providing additional training in SEM operation. The cost of this misdiagnosis was several thousand pounds.

FIRST AID HAS UNDERGONE FIELD trials at LEO Cambridge with the headquarters service team. We have since finalized the functions to be supported and expanded the knowledge base. We have formally trained domain experts, who will be responsible for teaching service engineers in its use. We have chosen to use a *planned obsolescence* strategy for scheduling maintenance and to ensure that expert system security cannot be compromised. Each version of First AID will be operational for nine months before it expires permanently. The goal is to ensure that only one version ever requires technical support at any given time. We expect this to simplify and ease the maintenance burden and, more important, to ensure that the knowledge base is revised and expanded at regular intervals. For security, the passwords can be changed frequently and any illegal copies of First AID will automatically expire. This reduces the risk that competitors might gain access to the commercially sensitive information within the knowledge base. The updated versions will be released to service engineers via LEO's secure bulletin-board system to reduce distribution costs.

The Cambridge University team will also assist LEO personnel in determining the extent and content of the domain-specific help files to be provided, including the division between information distributed with the expert system and information resident on a secure Web server accessible only to authorized engineers.

As we described earlier, the remote-control software requires a Web server either resident on the target SEM or on a computer linked to the SEM, and the customer's SEM must be accessible over the Web. LEO has also released software (NetSEM) that lets its customers remotely control their own SEMs for instrument sharing, collaboration, and other applications. We have since updated First AID to use NetSEM for remote diagnosis.

Clearly, issues of security must be addressed before such access will be permitted; both Cambridge University and LEO are considering these. However, the microscopy community remains very interested in using the Internet for remote microscopy. We hope that the tangible benefits of improved technical support combined with secure service will overcome any anxieties within the customer base, and are currently awaiting a decision by LEO to commit to global deployment of First AID. ■

WE HOPE THAT THE TANGIBLE BENEFITS OF IMPROVED TECHNICAL SUPPORT COMBINED WITH SECURE SERVICE WILL OVERCOME ANY ANXIETIES WITHIN THE CUSTOMER BASE.

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References

1. H. Eriksson, "Expert Systems as Knowledge Servers," *IEEE Expert*, Vol. 14, No. 3, May/June 1996, pp. 14–19.
2. N.H.M. Caldwell, B.C. Breton, and D.M. Holburn, "An Expert System for Fault Diagnosis in the Scanning Electron Microscope," *Applications and Innovations In Expert Systems IV*, SGES Publications, Cambridge, UK, 1996, pp. 177–188.
3. G. Chand et al., "World Wide Web Controlled SEM," *Scanning: The J. Scanning Microscopies*, Vol. 19, No. 4, June 1997, pp. 292–296.
4. P. Wayner, "New Videophones Starved for Bandwidth," *Byte*, Vol. 21, No. 5, May 1996, pp. 125–128.

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